BORESIGHT RADIATION OF A DIPOLE ANTENNA WITH A UNIFORM OR NON-UNIOFORM LEFT HANDED SUPERSTRATE

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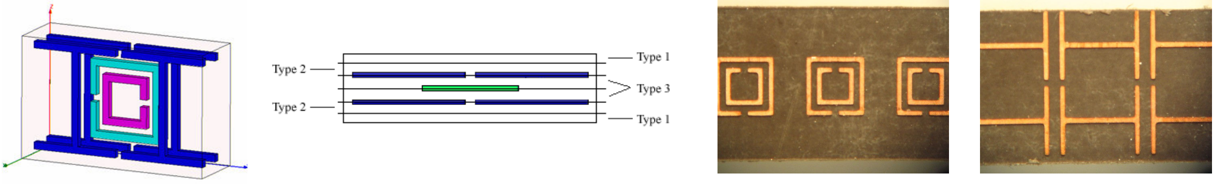
Abstract
In this paper measurements of the radiation performances of a dipole fed by a coaxial balun and a dipole with a left handed superstrate based on a finite periodic repetition of a unit cell are compared. Two types of superstrates, uniform and non-uniform, have been characterised in terms of impedance matching, resonant frequency and gain. First of all the dependence of the impedance matching and resonant frequency with the size of the superstrate has been analysed, having a good impedance matching and a decrease in the resonant frequency as the number of cells increase. By using an anechoic chamber and a receiver horn antenna, the power transmitted at boresight has been measured for different frequencies, observing a filtering behaviour due to the resonant characteristic of the superstrate and an improvement of the power transmitted at the resonant frequency of approximately 3 dB. Comparing the H and E plane radiation patterns of a dipole and the dipole with superstrate, more symmetrical and directive radiation patterns can be observed. Finally, a comparison between the simulated and measured aperture efficiency is presented with a good agreement.

I. Introduction
Nowadays, the study of the so-called Left Handed Materials (LHMs) has been increasing due to the enormous potential of this technology. Several recent papers have exposed the usefulness of these metamaterials (MTMs) for different applications [1]-[10]. LHMs can be understood as resonators with pass band and stop band properties at which the power is transmitted or reflected respectively. Up to now, volumetric MTMs working in the rejection bands have been used to create Artificial Magnetic Conductor (AMC) substrates for antennas [6]. Recently, applications of LHMs have shown the benefits of their pass band properties using them as superstrate of planar antennas to improve the directivity and reduce the back radiation [5]-[9]. Besides, new studies are proving that combining different resonant frequency MTMs in non-uniform superstrates, multi-frequency arrays with low coupling and distance between elements can be achieved [10].

In this paper a comparison between the radiation properties of a single dipole and a dipole with a uniform or non-uniform LH superstrate is presented. Measurements of the S_{11} parameter and the radiation pattern of uniform and non-uniform superstrates have been carried out for different sizes of the superstrate, i.e., varying the number of unit cells that form the superstrate. Finally, a comparison between the aperture efficiency obtained with these measurements and the one predicted by the simulations with Ansoft-HFSS is shown.

II. LHM superstrate
The left handed media used as superstrate of the dipole is a finite periodic structure based on the unit cell described in [3]-[5]. It consists of one Split Ring Resonator (SRR), or negative permeability element, between two pairs of Capacitively Loaded Strips (CLSs), or negative permittivity element, all embedded in a dielectric slab (see Fig. 1).

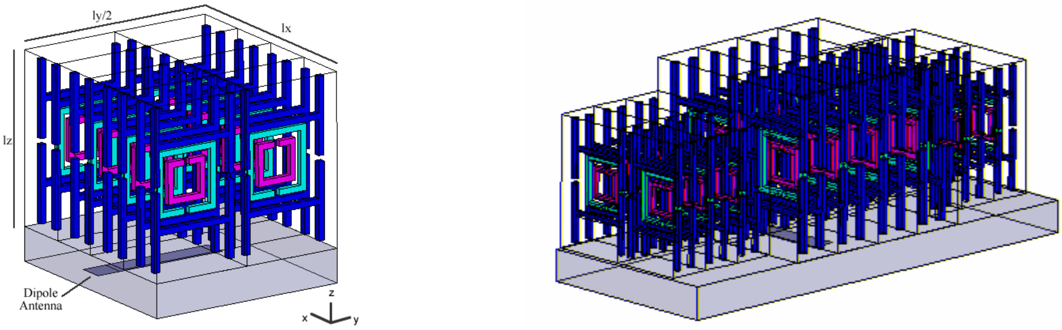


(a) (b) (c) (d)

Fig. 1. (a) Geometry of the LHM unit cell (b) Layers of one period (c) Detail of the SRRs (d) Detail of the CLSs.

In order to construct a unit cell, a layer by layer technique described in detail in [5] is followed. Each period is created by stacking six layers, 2 layers of each of the three types, following the pattern 123321 (see Fig. 1(b)). Using this fabrication technique, the number of periods that constitute the superstrate is not fixed, but can be modified by varying the number of layers that are stacked.

Tuning the resonant frequency of a dipole antenna to the one of the superstrate, the power will be transmitted and radiated through the cells. However, if higher resonant frequency unit cells are used as superstrate, the power radiated by the dipole will be reflected. Moreover, combining transmitting and reflecting cells, non-uniform superstrates can be constructed. This fact can be used to create multi-frequency antennas by tuning dipoles to the different resonant frequencies of the groups of unit cells that form the superstrate. Fig. 2 (a) shows the configuration of a dipole antenna without ground plane and with a uniform superstrate formed by 4 transmitting cells and Fig. 2 (b) the configuration of a non-uniform superstrate made-up by 4 transmitting central cells surrounded by 3 reflecting ones, or higher resonant frequency cells, on each side.



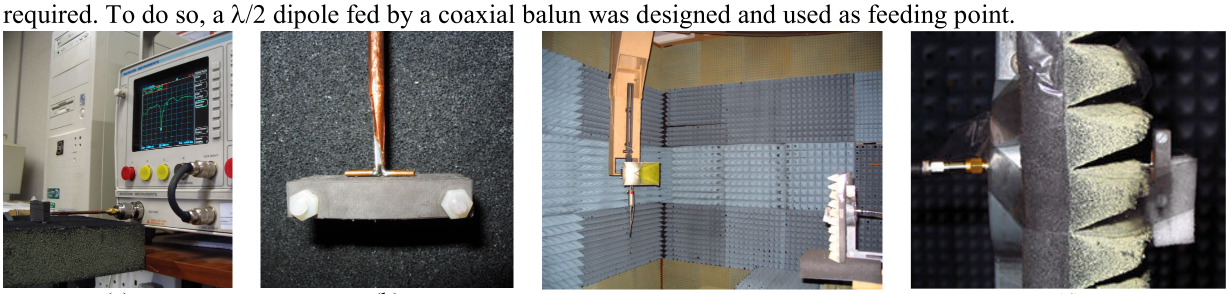
(a) (b)

Fig. 2. (a) Geometry of the uniform superstrate (b) Geometry of the non-uniform superstrate.

III. Radiation performances

In order to check the improvements in the radiation performances of a dipole when a LH superstrate is used, the S_{11} parameter and the radiation pattern have been measured and compared with the case of a single dipole.

To excite correctly the superstrate, an E field parallel to the CLSs and an H field axial to the SRRs are required. To do so, a $\lambda/2$ dipole fed by a coaxial balun was designed and used as feeding point.



(a) (b) (c) (d)

Fig. 3. (a) (b) Set-up for the measurements of the S_{11} parameter. (c) (d) Set-up for the measurements of the radiation patterns.

A. S_{11} Parameter

First of all, the S_{11} parameter of the dipole with the uniform and non-uniform superstrates was measured by using a network analyser. The set up of the measurements is shown in Fig. 3 (a) and (b).

The influence of the LHM superstrate in the impedance matching performances of the dipole was analyzed by varying the number of periods of the superstrate from 2 to 12. The magnitude of the S_{11} parameter vs the frequency for all the different configurations measured is shown in Fig. 4 (a). The same analysis was carried out for the non-uniform superstrate. For each fixed number of transmitting cells, the number of surrounding reflecting ones was varied from 0 to 5. Fig. 4 (b) shows the results for the case of 6 transmitting cells surrounded by X (from 0 to 5) reflecting ones (Xr6tXr). A matching better than -12 dB has been obtained for all the cases.

Considering the resonant frequency as the one of the minimum S_{11}, it can be observed that as the number of cells increases, the resonant frequency decreases, being much more stable for the non-uniform superstrate. In the case of the uniform superstrate, a variation from 11.36 GHz for 2 cells to 10.96 GHz in the case of 12 cells can be observed.

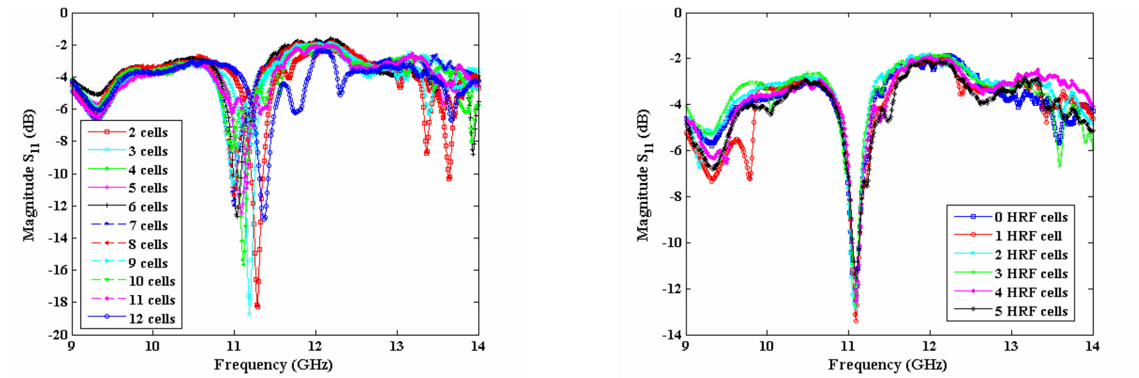


Fig. 4. Magnitude of the S_{11} parameter vs frequency. (a) Uniform superstrate (b) Non-uniform superstrate.

B. Radiation Pattern

The next step in the characterization of the enhancement of the radiation performances due to the use of the superstrate was the measurement of the E and H plane radiation patterns. To do so, a half anechoic chamber with a horn antenna as receiver and the dipole (with and without superstrate) as transmitter were used. The position of the superstrate was selected in order to maximize the power received at boresight, i.e., the position of maximum gain. Some pictures of the set-up of the measurements are shown in Fig. 3 (c) and (d).

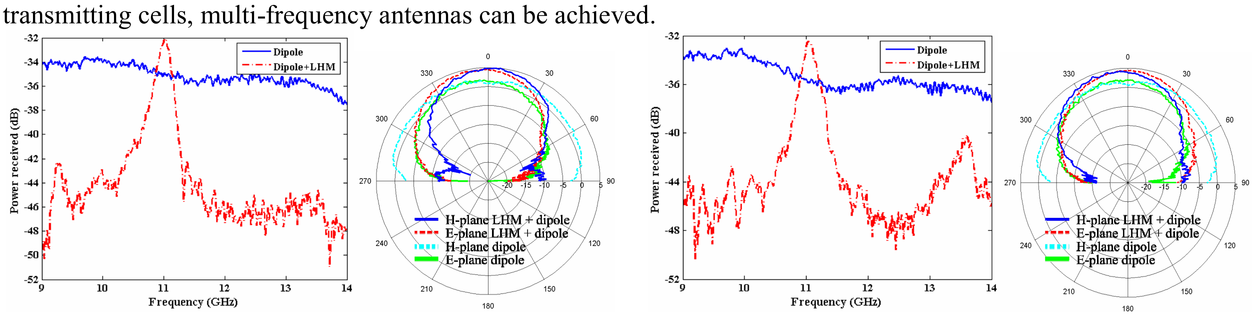
Analysing the power received vs the frequency (see Fig. 5), a filtering behaviour can be observed due to the pass band properties of the superstrate. Comparing this power received when the dipole has the superstrate with the case of the single dipole, an enhancement around the resonant frequency of the superstrate can be observed. Out of this band, a rejection of around -10 dB has been obtained.

Measuring the radiation pattern (power received P_R) at that resonant frequency and taking into account the power transmitted P_T, the gain of the receiver horn antenna G_R, the distance between antennas d and the working frequency λ, the gain of the transmitting antenna G_T can be calculated by applying the Friis equation(1).

$$G_T = 20\log\left(\frac{4\pi d}{\lambda}\right) + P_R - P_T - G_R \tag{1}$$

As in the case of the S_{11}, a parametric analysis has been carried out varying the number of cells from 2 to 12. Fig. 5 (a) shows the results obtained in the case of a uniform superstrate with 9 transmitting periods. Looking at the frequency sweep of the power received, an enhancement of 3 dB at the resonant frequency of 11 GHz can be observed. Comparing the radiation patterns with and without superstrate at that frequency, it can be seen that the H and E planes for the superstrate case are more symmetrical and directive.

Similar results have been obtained for the non-uniform superstrate. Fig. 5 (b) shows these results for the non-uniform superstrate formed by 6 central transmitting cells surrounded by 4 reflecting ones on each side. This allows us to affirm that the behaviour of the whole configuration is not affected by the presence of reflecting cells on the corners. As it has been commented, tuning dipoles to the resonant frequency of the reflecting and transmitting cells, multi-frequency antennas can be achieved.



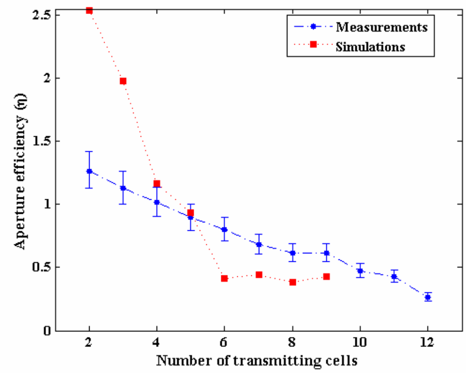
(a) (b)

Fig. 5. Power received vs frequency and H and E plane radiation pattern. (a) Uniform and (b) Non-Uniform superstrate.

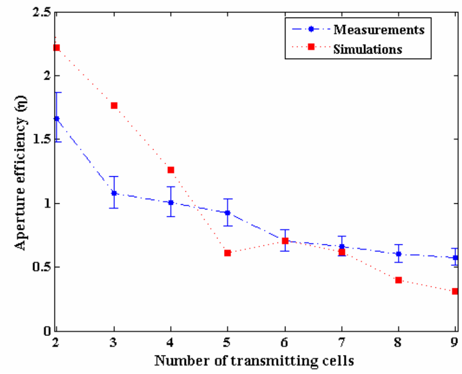
C. Aperture Efficiency

Once the gain G of the configuration is known, the aperture efficiency (η) of the configuration can be calculated following $G=(4\pi/\lambda^2)\,\eta\, A_{phys}$, where A_{phys} is the physical area of the superstrate.

A comparison between the aperture efficiency achieved with the measurements and the one of the simulations for the different number of transmitting cells analysed can be seen in Fig. 6 (a) and (b) for the uniform and non-uniform superstrate respectively. A good agreement between them can be observed.



(a)



(b)

Fig. 6. Aperture efficiency vs the number of transmitting cells. (a) Uniform superstrate. (b) Non-uniform superstrate.

Due to the small dimensions of the superstrates, there is field on the edges of the superstrate so the radiation area is higher than the physical area. As a result, the aperture efficiency is larger than one. It can be observed that as the number of cells increases, the efficiency decreases. Although the gain increases with the number of cells, the ratio of increasing surface is higher, so the efficiency decreases. Besides, as the physical area increases, the edge effect decreases, achieving an expected result of an aperture efficiency smaller than one, but higher than 80 % until six cells.

IV. Conclusions

In this paper the radiation performances of a dipole and a dipole with uniform or non-uniform LH superstrate are compared. A parametric analysis of the influence of the superstrate in the radiation performances of the configuration has been carried out varying the number of periods of the superstrate. In all cases, a good impedance matching was obtained with a S_{11} parameter smaller than -12 dB at the resonant frequency. It was observed that when the number of periods increases, the resonant frequency decreases. Measuring the power transmitted at boresight by the dipole with superstrate and comparing with the one radiated by the single dipole, an enhancement of approximately 3 dB was achieved around the resonant frequency of the superstrate. Comparing the H and E plane radiation patterns at that frequency, more symmetrical and directive radiation patterns can be observed with this new configuration. Finally, it has been observed that the aperture efficiency decreases with the number of cells being larger than 80 % until 6 cells.

Acknowledgements

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